Decadal-Scale response of the Antarctic Ice Sheet to a warming ocean using the POPSICLES coupled ice sheet-ocean model

Dan Martin

Lawrence Berkeley National Laboratory

July 13, 2016

U.S. DEPARTMENT OF ENERGY | Office of Science

BISICLES

BERKELEY LAB

PIK

Los Alamos NATIONAL LABORATORY EST. 1943

University of BRISTOL

Toward Decadal-Scale response of the Antarctic Ice Sheet to a warming ocean using the POPSICLES coupled ice sheet-ocean model

Dan Martin

Lawrence Berkeley National Laboratory

July 13, 2016

U.S. DEPARTMENT OF ENERGY | Office of Science | BISICLES | BERKELEY LAB | PIK | Los Alamos NATIONAL LABORATORY EST. 1943 | University of BRISTOL

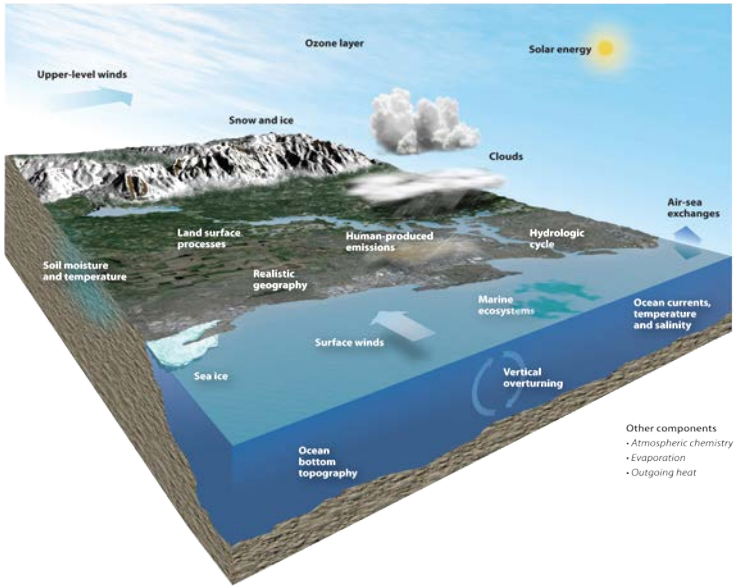
Joint work with:

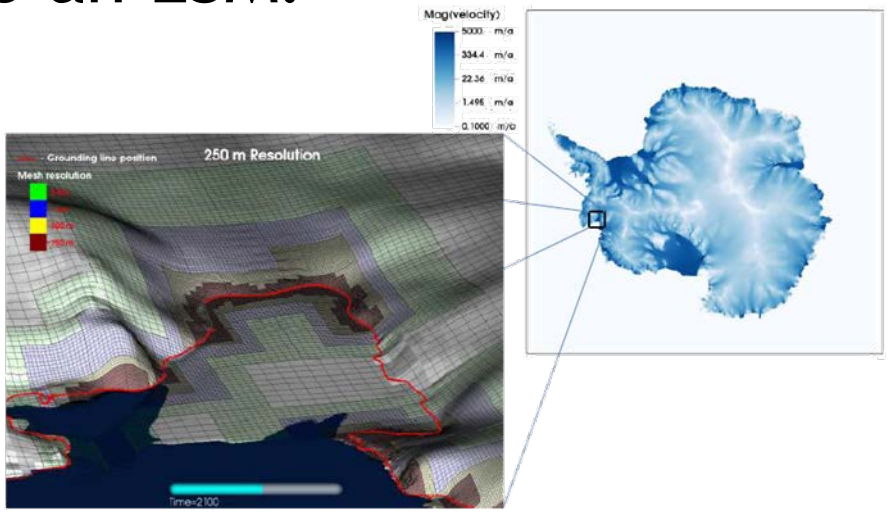
- **Xylar Asay-Davis** (Potsdam-PIK)
- Stephen Cornford (Bristol)
- Stephen Price (LANL)
- Doug Ranken (LANL)
- Mark Adams (LBNL)
- Esmond Ng (LBNL)
- William Collins (LBNL)

- Work supported by US Department of Energy

Big Picture -- target

- Aiming for coupled ice-sheet-ocean modeling in ESM
- Multi-decadal to century timescales
- Target resolution:
  - Ocean: 0.1 Degree
  - Ice-sheet: 500 m (adaptive)
- Why put an ice-sheet model into an ESM?
  - fuller picture of sea-level change
  - feedbacks may matter on timescales of years, not just millennia



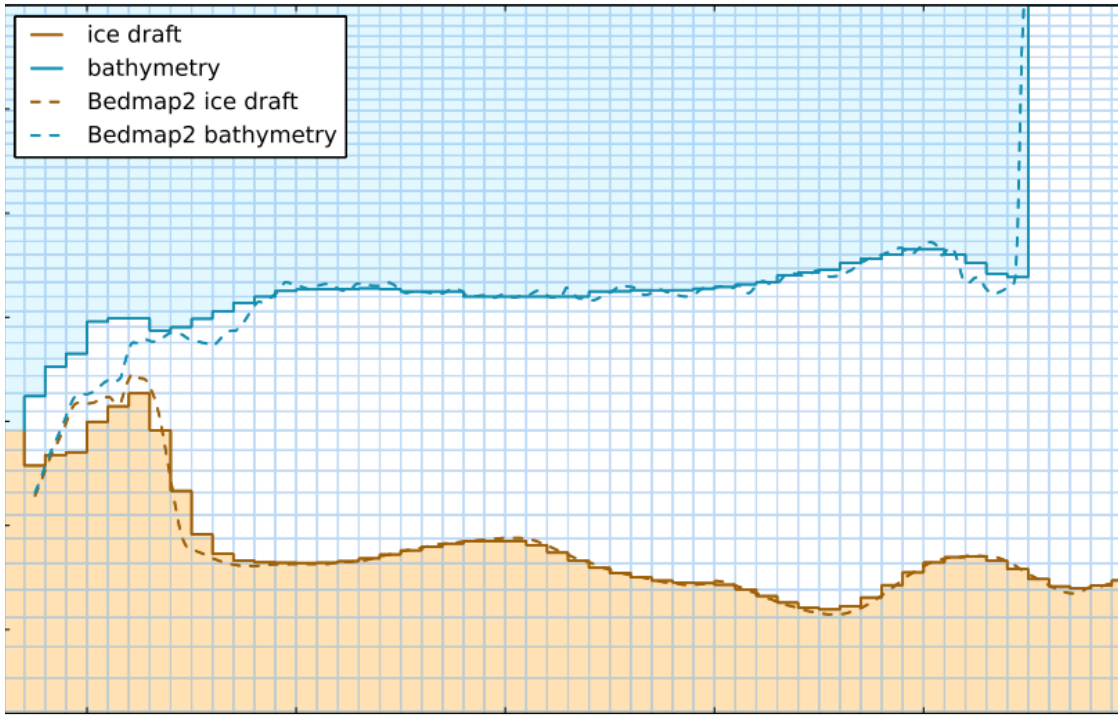


Coupled Ice and Ocean Models:

- Ocean Circulation Model: POP2x
- Ice Sheet: BISICLES (CISM-BISICLES)
- POP + BISICLES = POPSICLES

POP and Ice Shelves

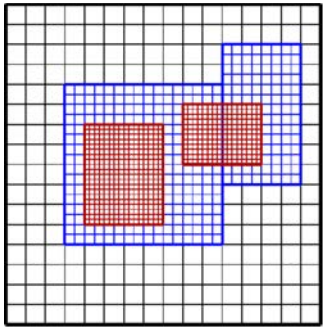
- Parallel Ocean Program (POP) Version 2
  - Ocean model of the Community Earth System Model (CESM)
  - z-level, hydrostatic, Boussinesq
- Modified for Ice shelves:
  - partial top cells
  - boundary-layer method of Losch (2008)

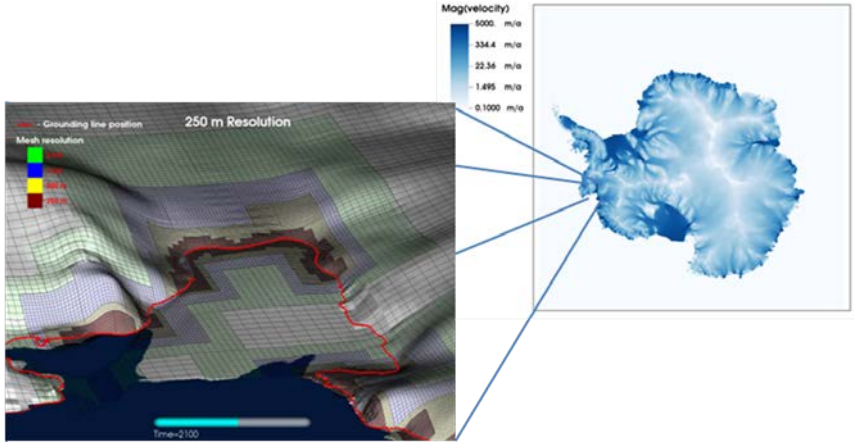


- Melt rates computed by POP (Jenkins 3-equation formulation):
  - sensitive to vertical resolution
  - nearly insensitive to transfer coefficients, tidal velocity, drag coefficient

BISICLES Ice Sheet Model

- Scalable adaptive mesh refinement (AMR) ice sheet model
  - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (U.K.) and LANL
- Variant of "L1L2" model (SSA*) (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin…





Coupling: Synchronous-offline

- Monthly coupling time step ~ based on experimentation
- BISICLES → POP2x: (instantaneous values)
  - ice draft, basal temperatures, grounding line location
- POP2x → BISICLES: (time-averaged values)
  - (lagged) sub-shelf melt rates
- Coupling offline using standard CISM and POP netCDF I / O
- POP bathymetry and ice draft recomputed:
  - smoothing bathymetry and ice draft, thickening ocean column, ensuring connectivity
  - T and S in new cells extrapolated iteratively from neighbors
  - barotropic velocity held fixed; baroclinic velocity modified where ocean column thickens/thins

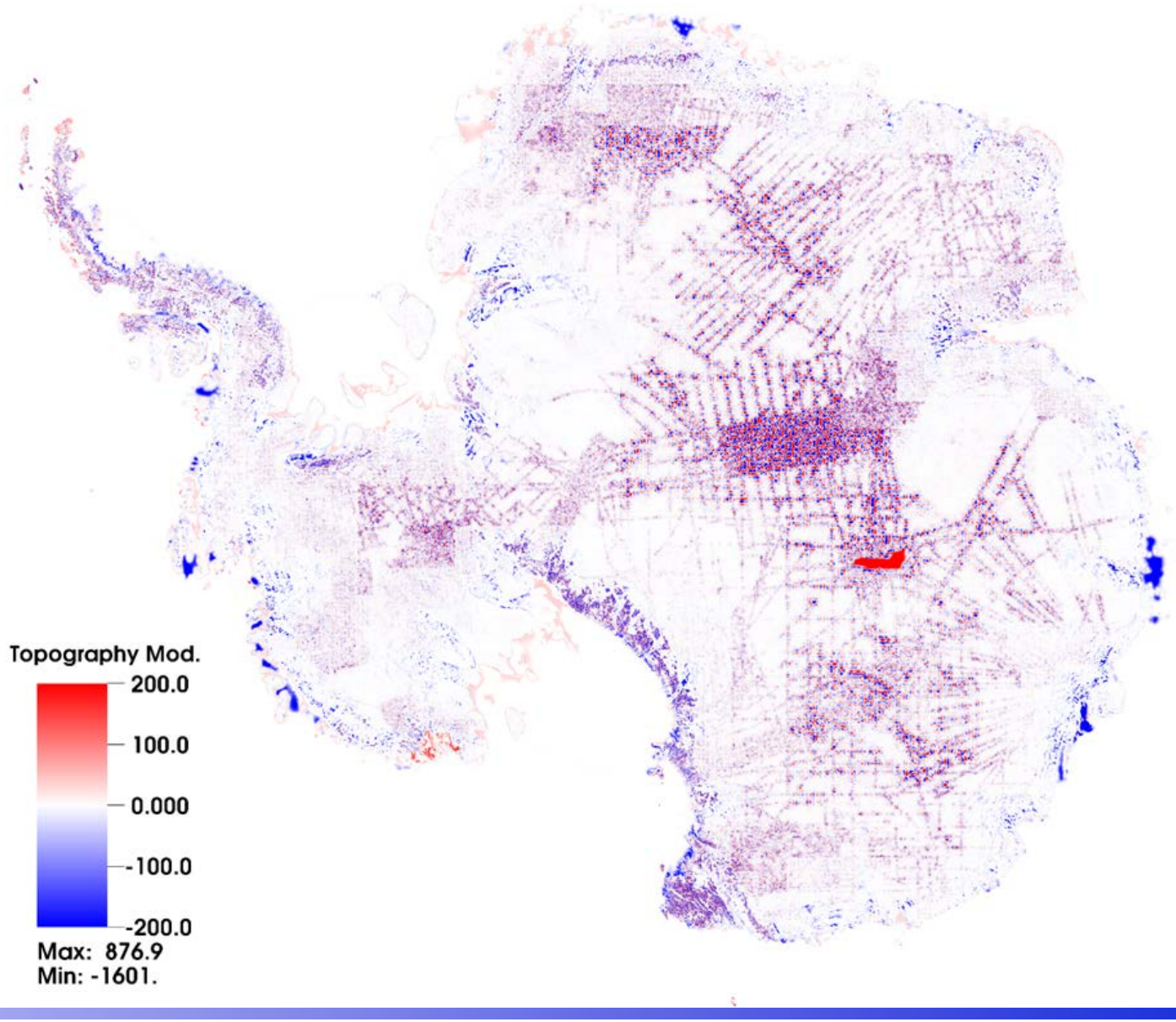
Lessons learned from previous attempts

- Need better topography/bathymetry (modify Bedmap2)
  - Bathymetry – unrealistically thin subshelf cavities prone to grounding instability in fully-coupled context.
  - Topography – unmodified Bedmap2 inconsistent
    - Result -- large flux divergences at early times
    - attempts to fix with synthetic mass balance doomed

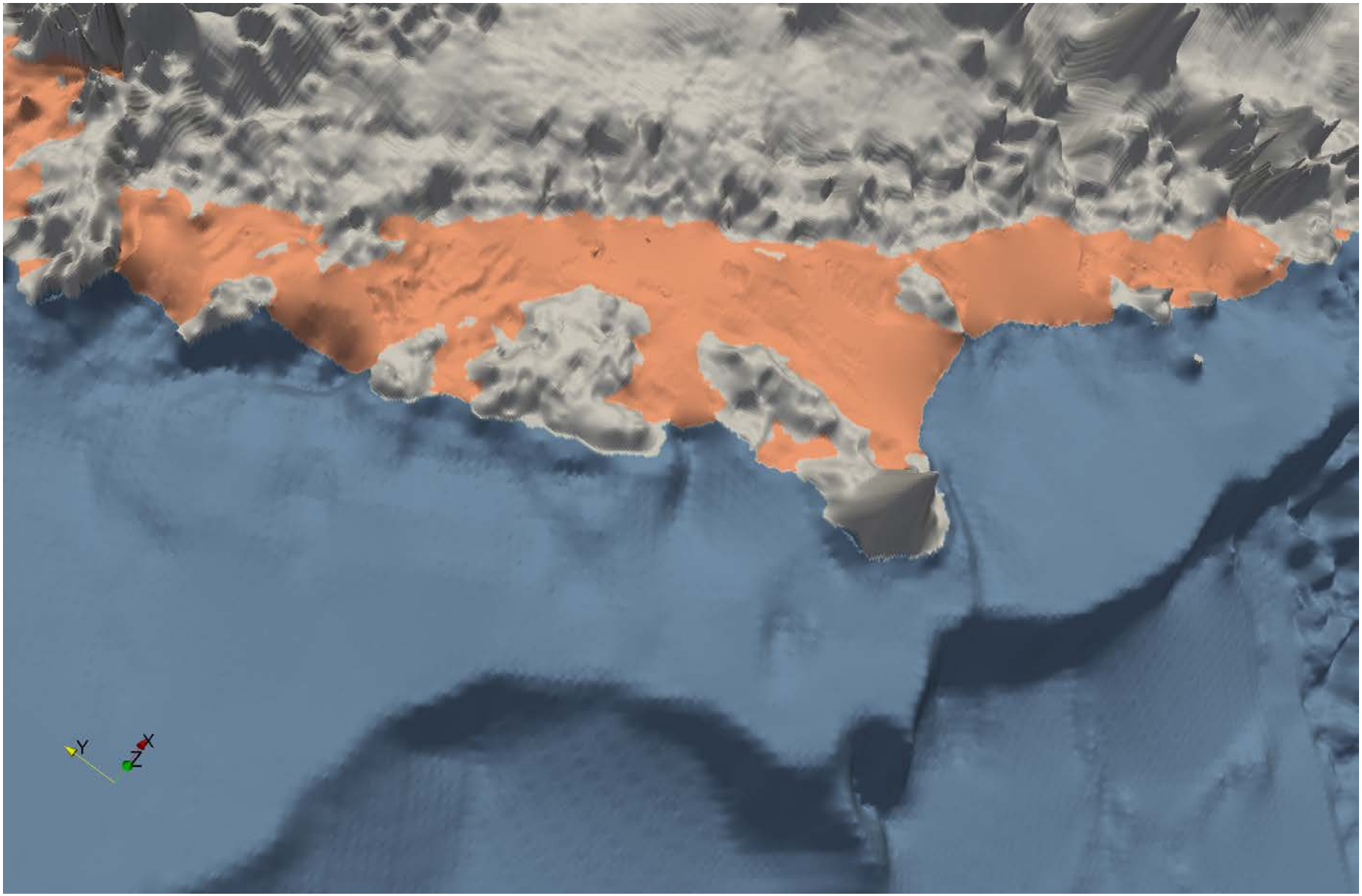
Modifying Bedmap2 for Coupled Runs

- Where possible, preserve upper ice surface
- Approach for modifying bathymetry:
  - Use new observations (Greenbaum et al, 2015) for Totten.
  - Use RTOPO1 to deepen (rather than simply replace) bathymetry under most ice shelves in the Amundsen and Bellingshausen regions.
  - Cavities under Dalton, Nivlisen, Shackleton, and Stange ice shelves thickened based on the distance from the grounding line. (ad hoc)
  - Smooth discontinuities between grounded and floating sections.
  - Topography under grounded ice was deepened in regions (Rutford, Pine Island Ice Streams) to better match velocity observations (mass-conserving bed (Nais et al, 2015, Cornford et al, 2016)).

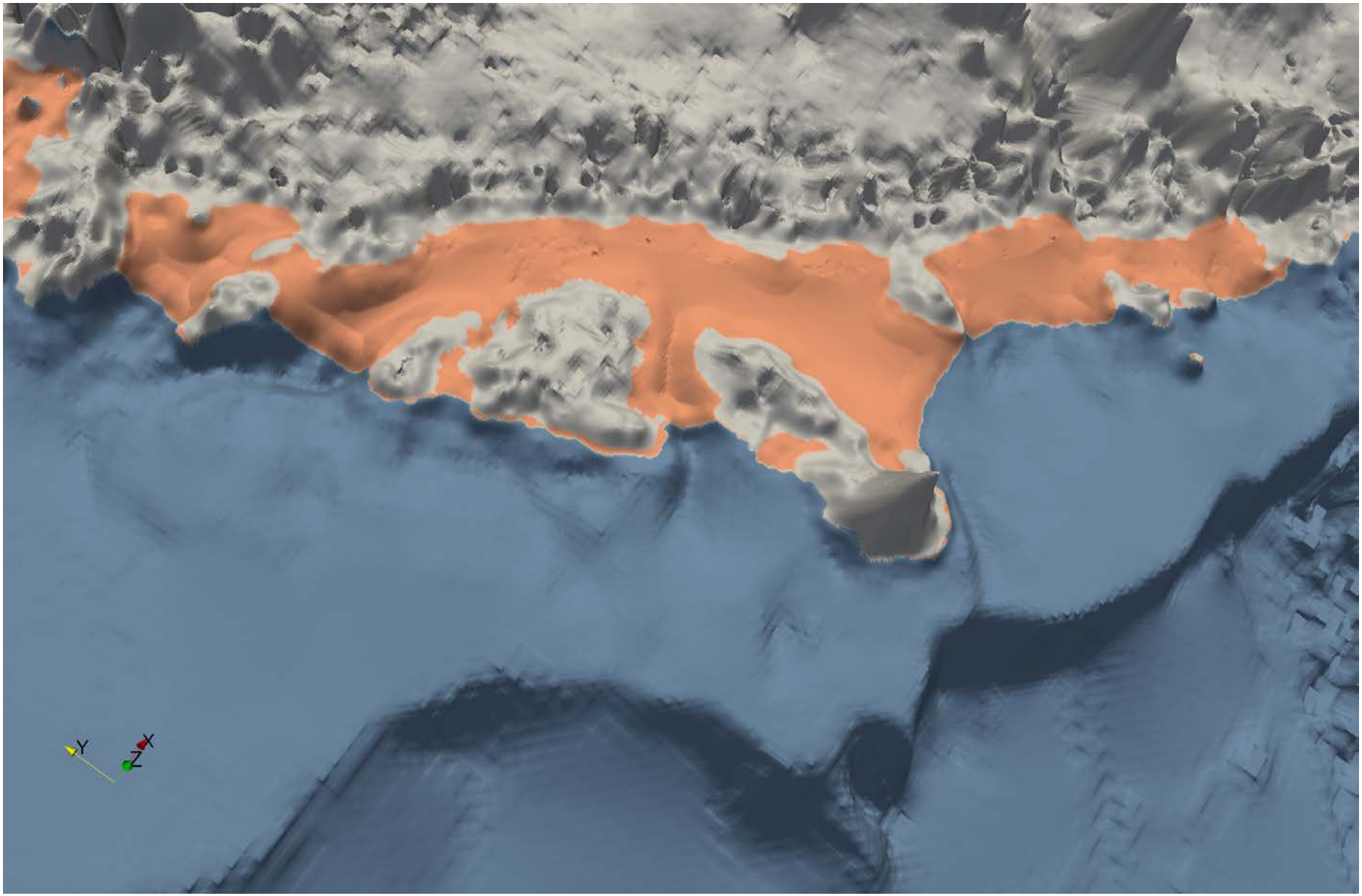
Bedmap Modifications



Getz - Bedmap2



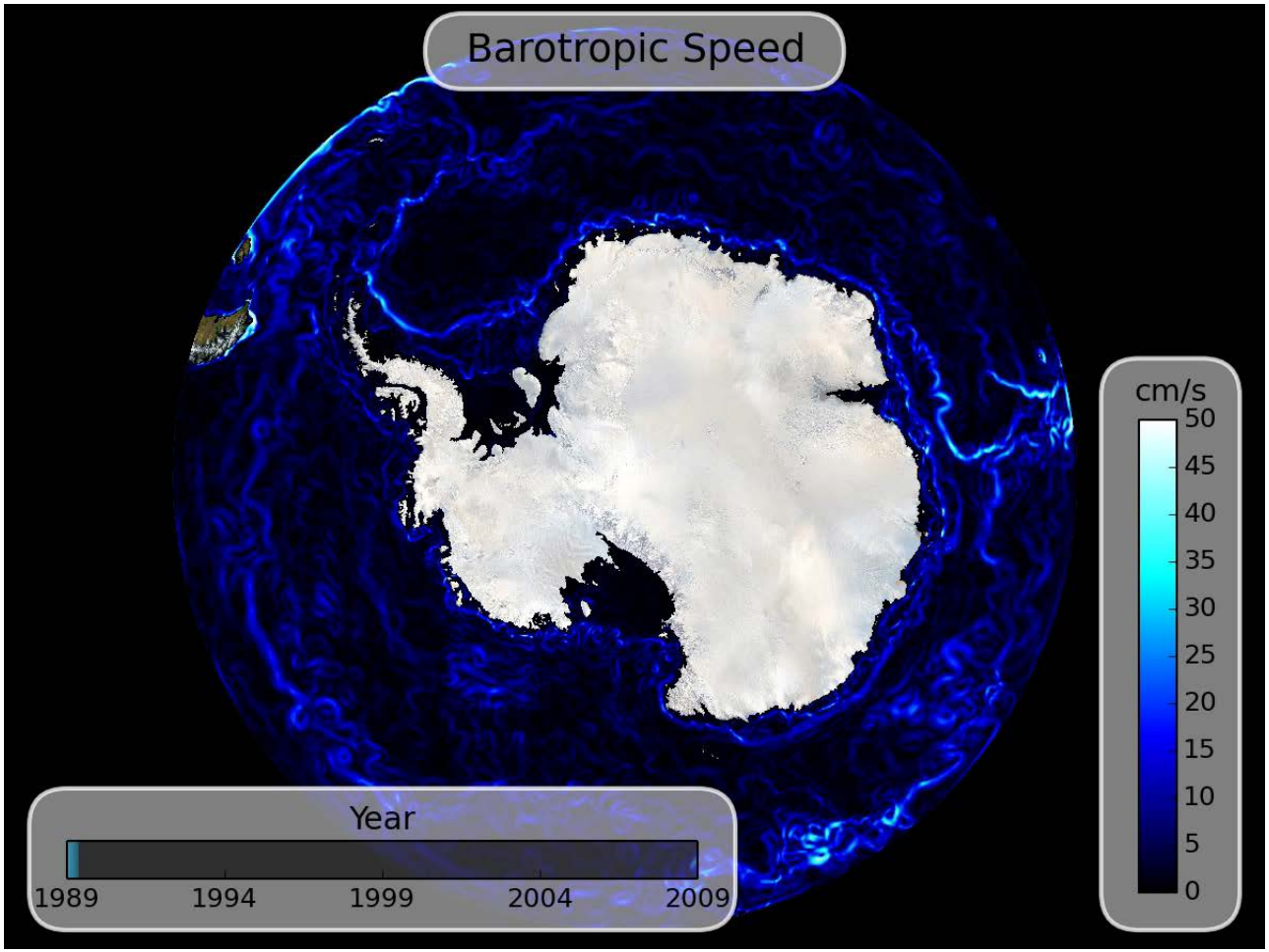
Getz - modified



Antarctic-Southern Ocean Coupled Simulations

POP setup:

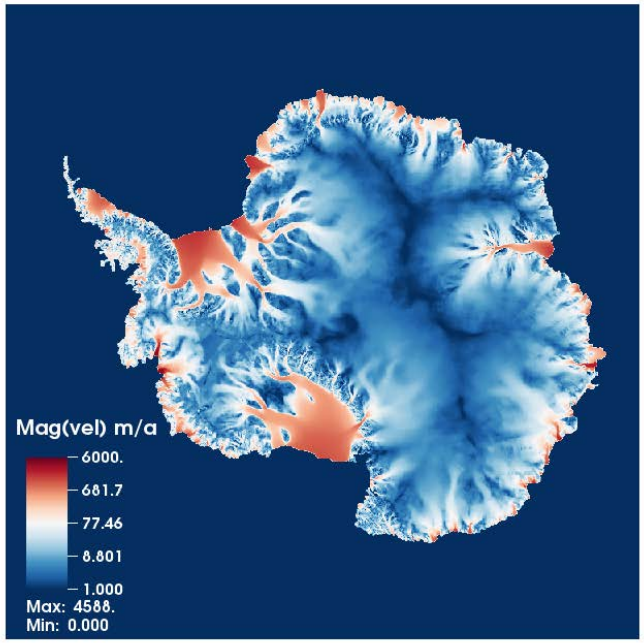
- Regional southern ocean domain (50-85°S)
- ~5 km (0.1°) horizontal res.
- 80 vertical levels (10m - 250m)
- Initialize with stand-alone (20 years) run;
- Bedmap2 geometry
- Force with CORE v2 "Normal Year"forcing
- Monthly restoring to WOA at northern boundary

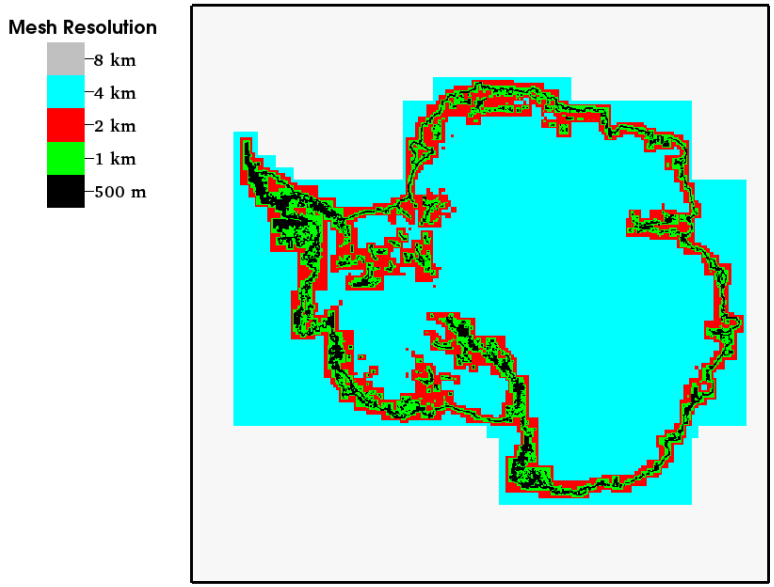


Antarctic-Southern Ocean Coupled Simulations

BISICLES setup:

- Full-continent modified Bedmap2 (Fretwell, 2013) geometry
- Temperature field from Pattyn (2010)
- Initialize to match Rignot (2011) velocities (inverse problem)
- 500m finest resolution (adaptive mesh refinement)
- SMB field from Arthern

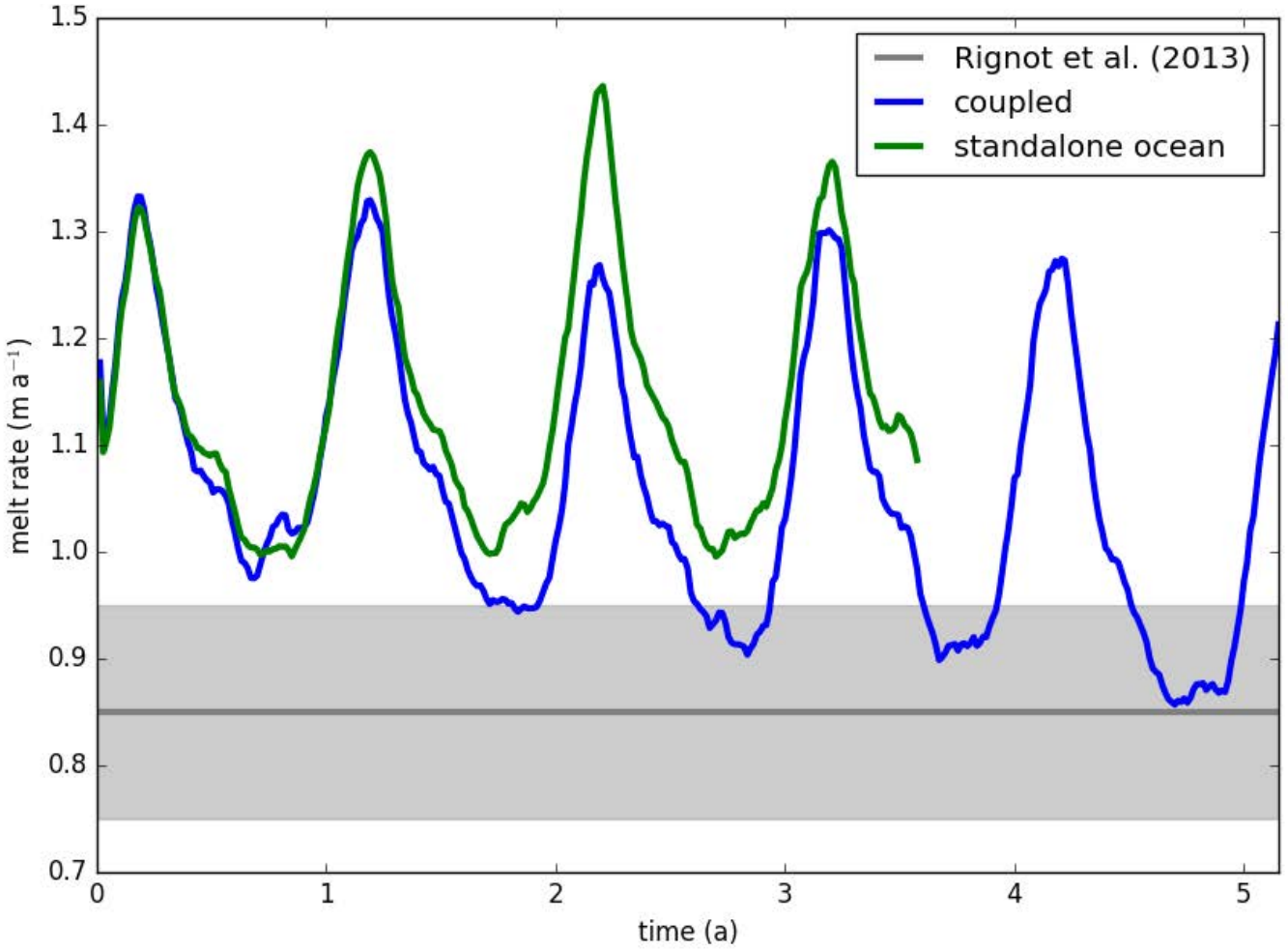




Then hit "go"…

Work in progress – about 5 years in…

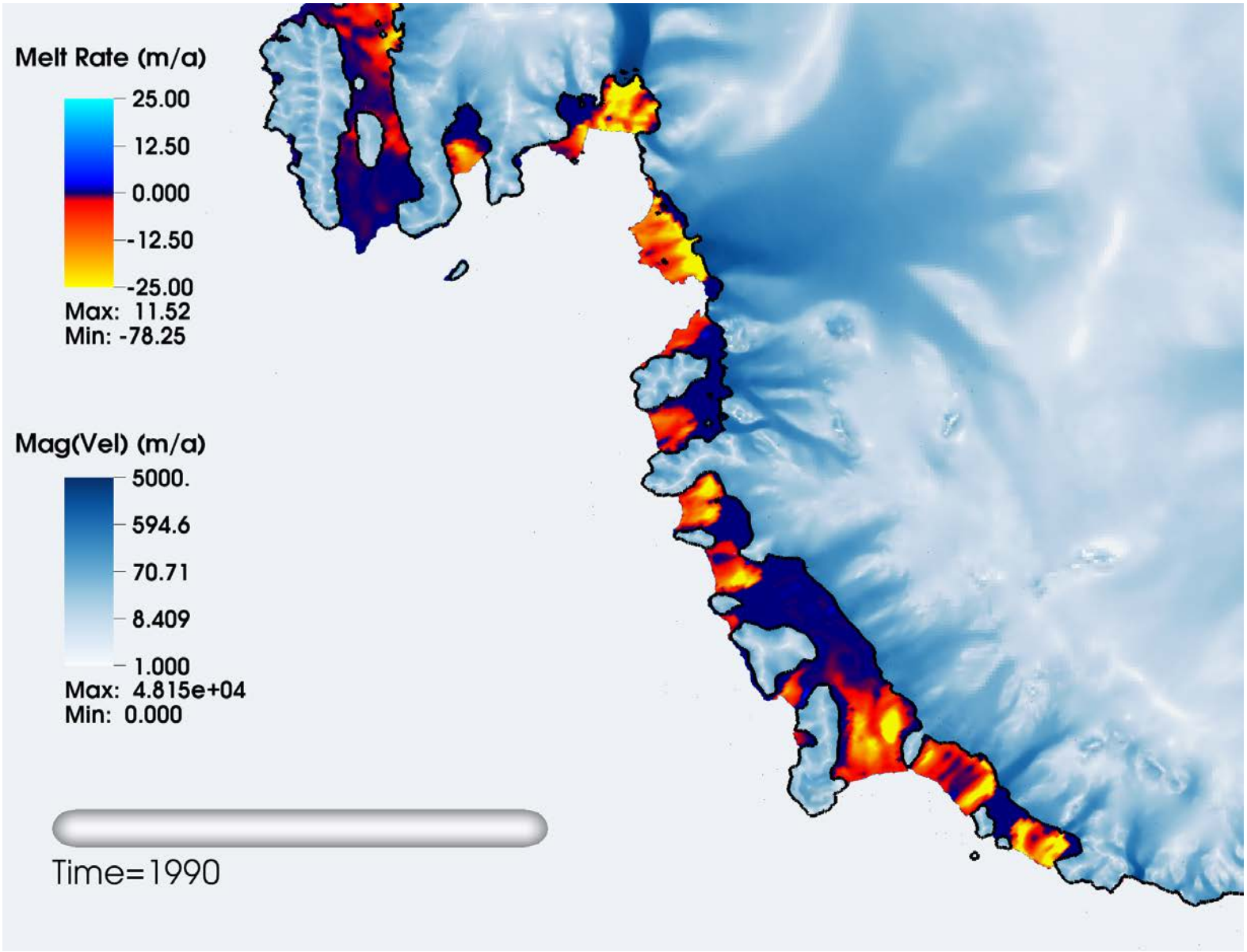
POP-computed Melt rates



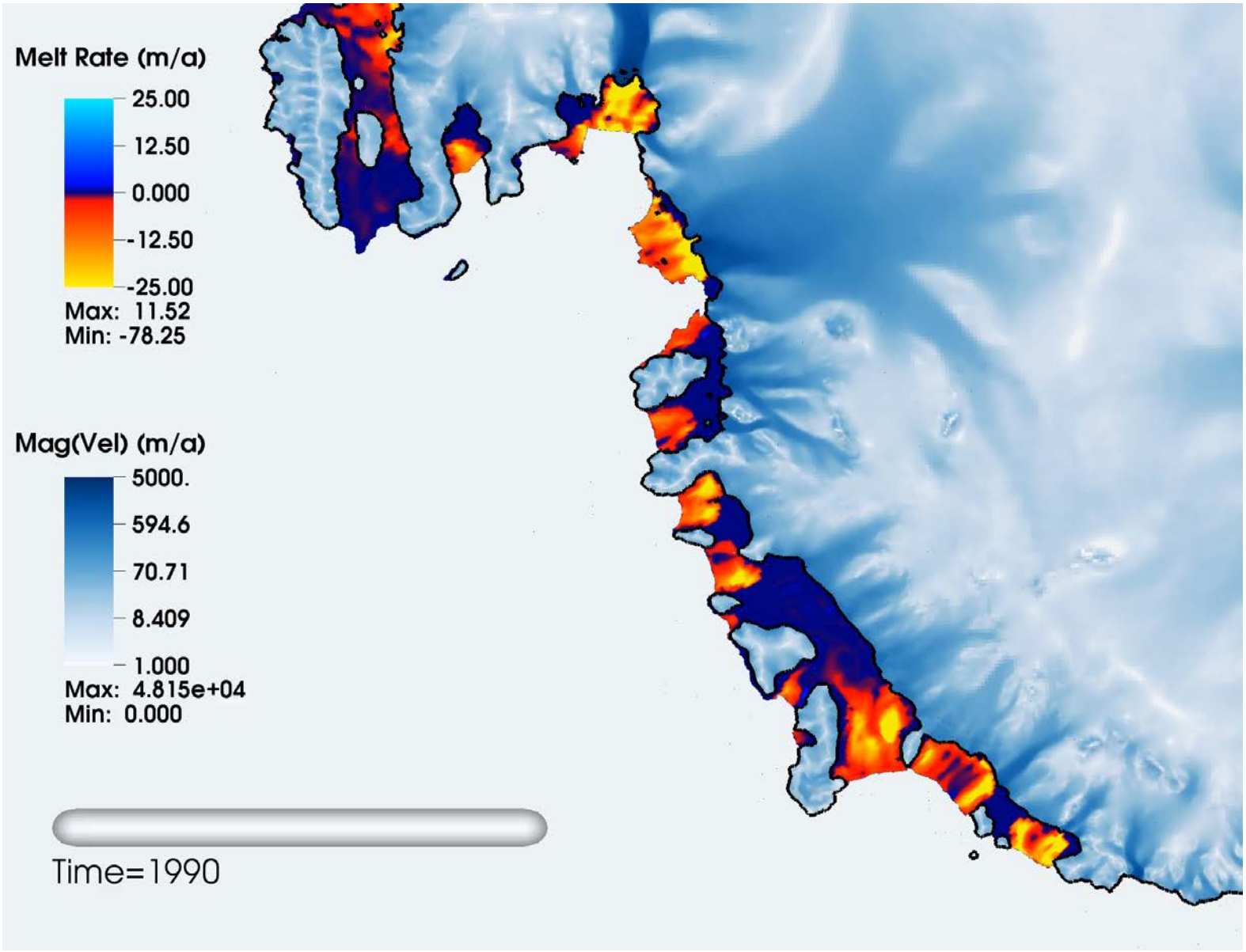
Too much melting (warm bias due to mixing of CDW into upper ocean, too much stratification from freshwater forcing – ocean model issue.)

Ice statistics

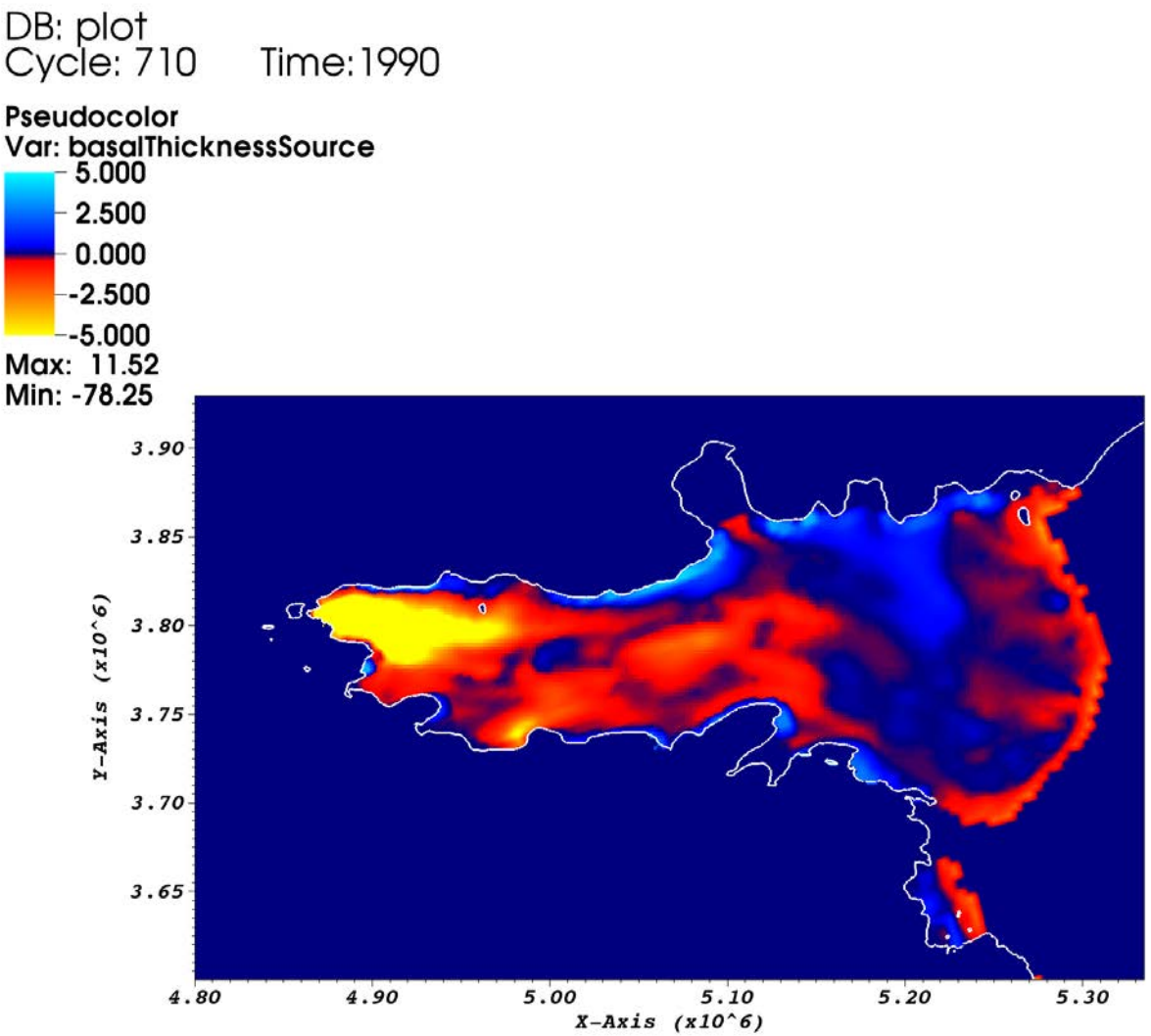
Getz and Amundsen Sea



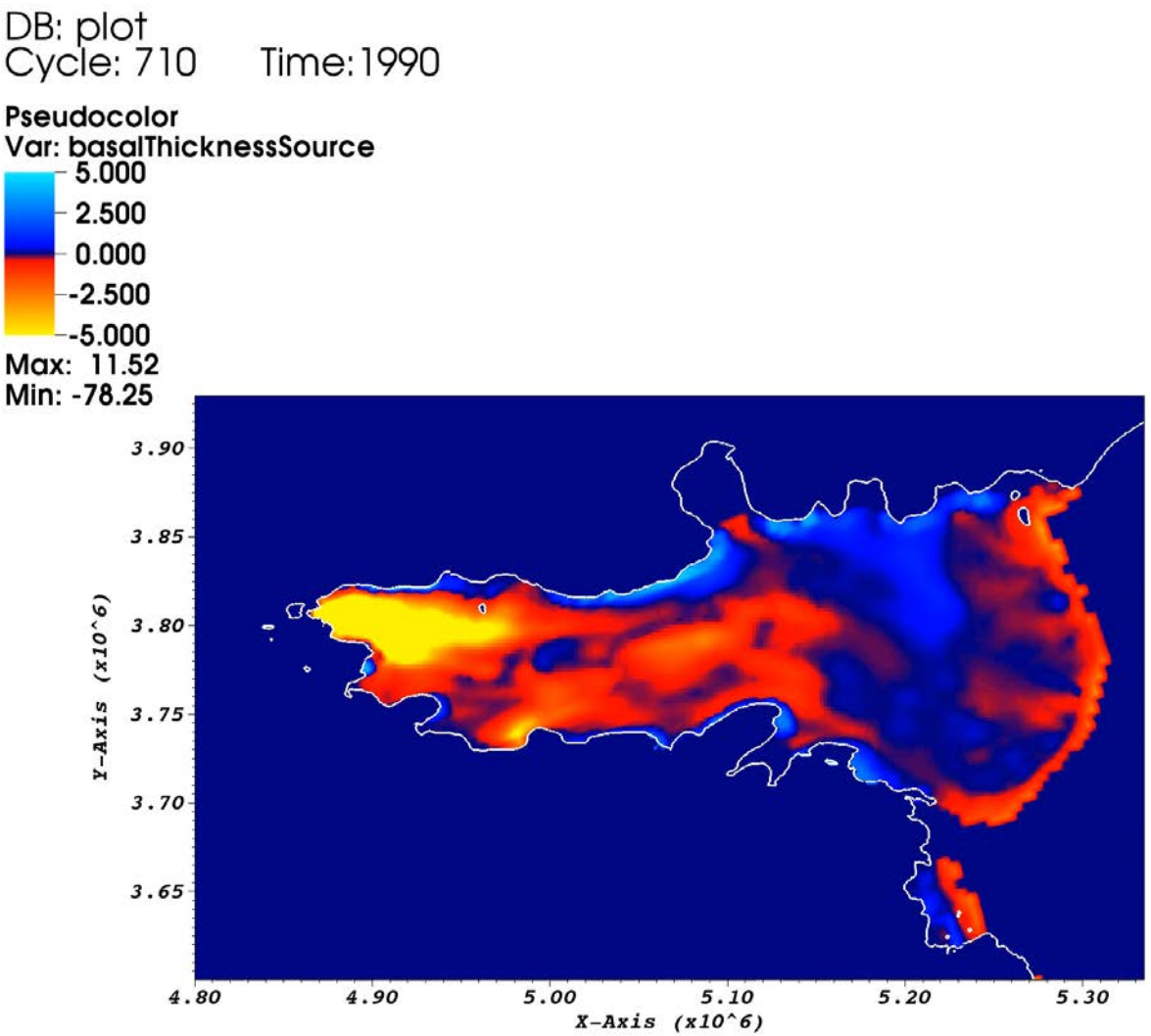
Getz and Amundsen Sea



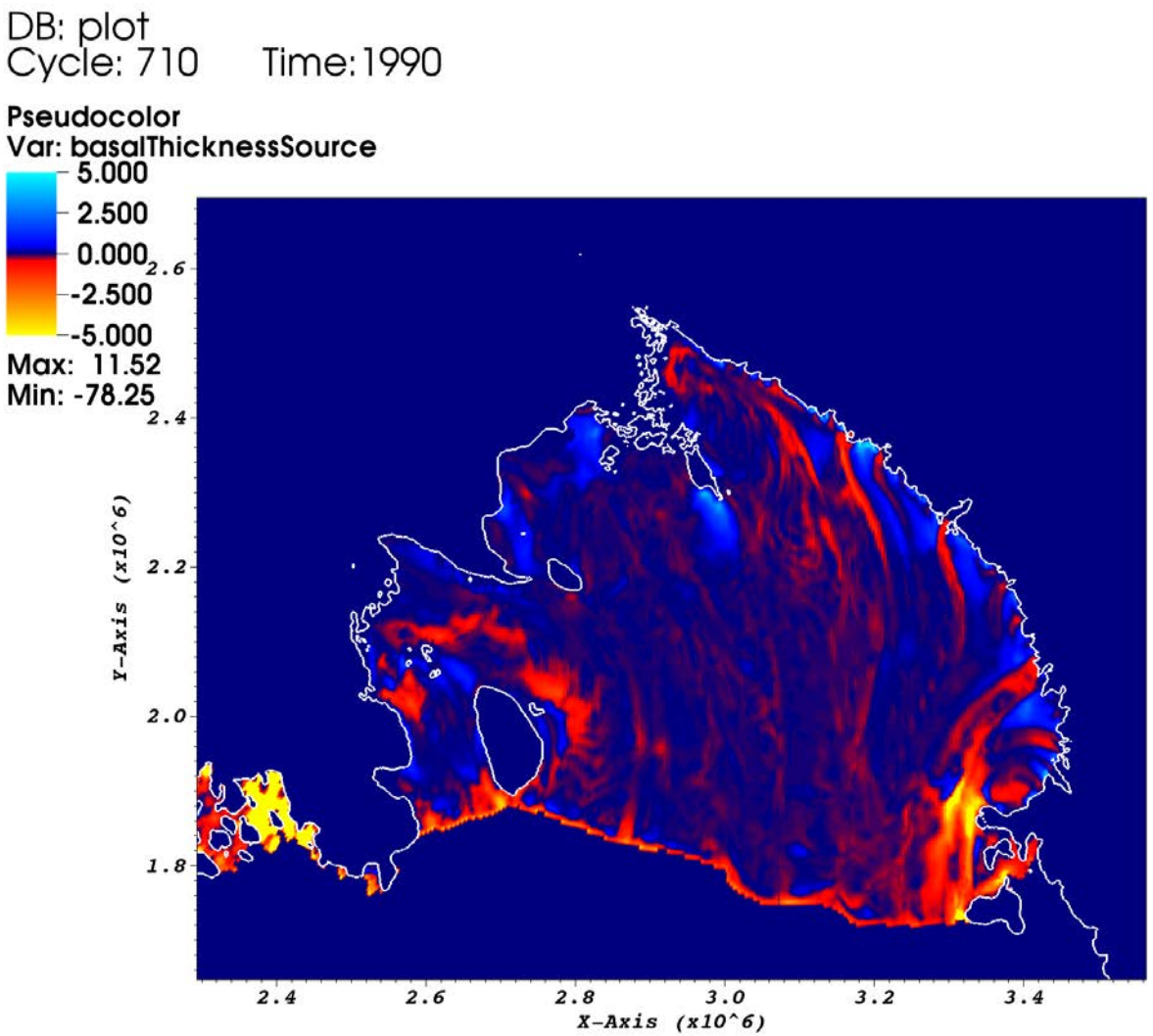
Amery:


DB: plot
Cycle: 710 Time:1990
Pseudocolor
Var: basalThicknessSource
5.000
2.500
0.000
-2.500
-5.000
Max: 11.52
Min: -78.25
3.90
3.85
3.80
3.75
3.70
3.65
Y-Axis (x10^6)
4.80
4.90
5.00
5.10
5.20
5.30
X-Axis (x10^6)

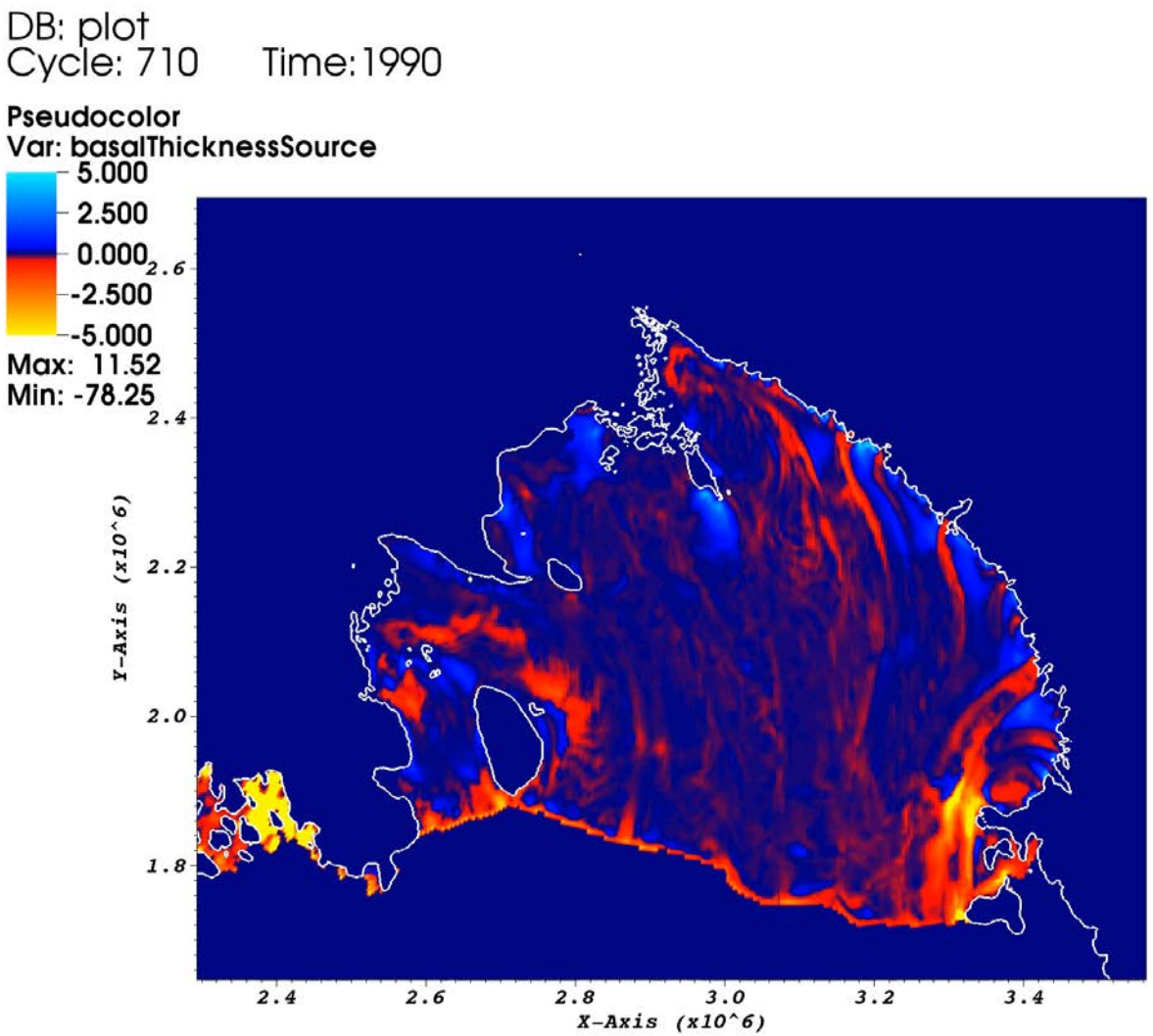
Amery:


DB: plot
Cycle: 710 Time:1990
Pseudocolor
Var: basalThicknessSource
5.000
2.500
0.000
-2.500
-5.000
Max: 11.52
Min: -78.25
3.90
3.85
3.80
3.75
3.70
3.65
Y-Axis (x10^6)
4.80
4.90
5.00
5.10
5.20
5.30
X-Axis (x10^6)

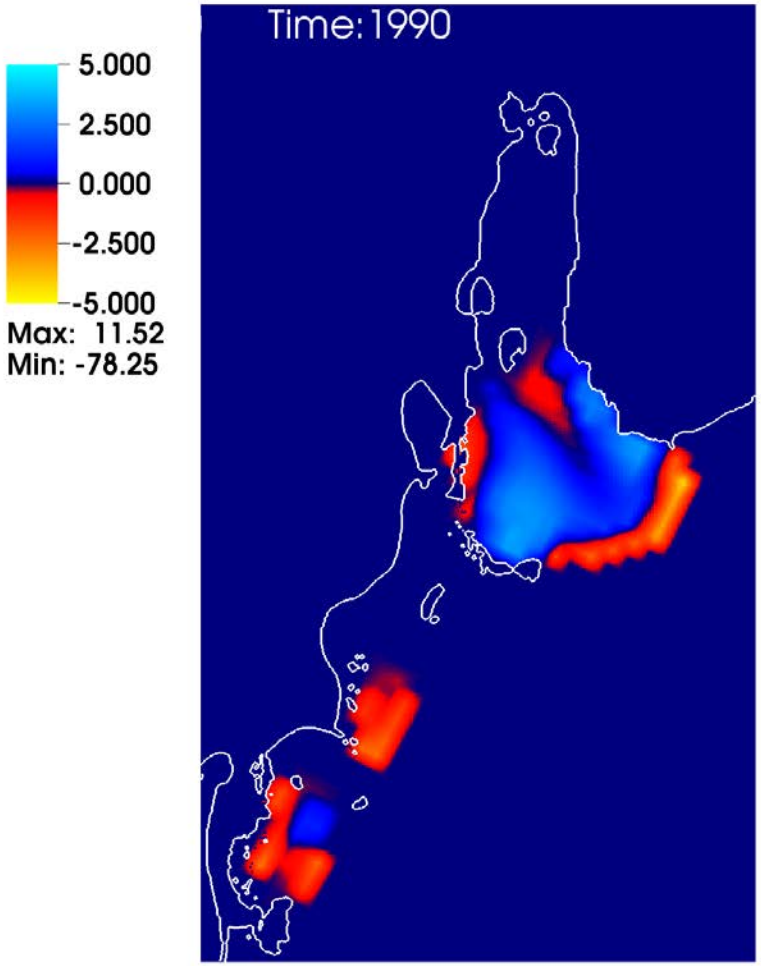
Ross:


DB: plot
Cycle: 710 Time:1990
Pseudocolor
Var: basalThicknessSource
5.000
2.500
0.000
-2.500
-5.000
Max: 11.52
Min: -78.25
Y-Axis (x10^6)
2.6
2.4
2.2
2.0
1.8
2.4
2.6
2.8
3.0
3.2
3.4
X-Axis (x10^6)

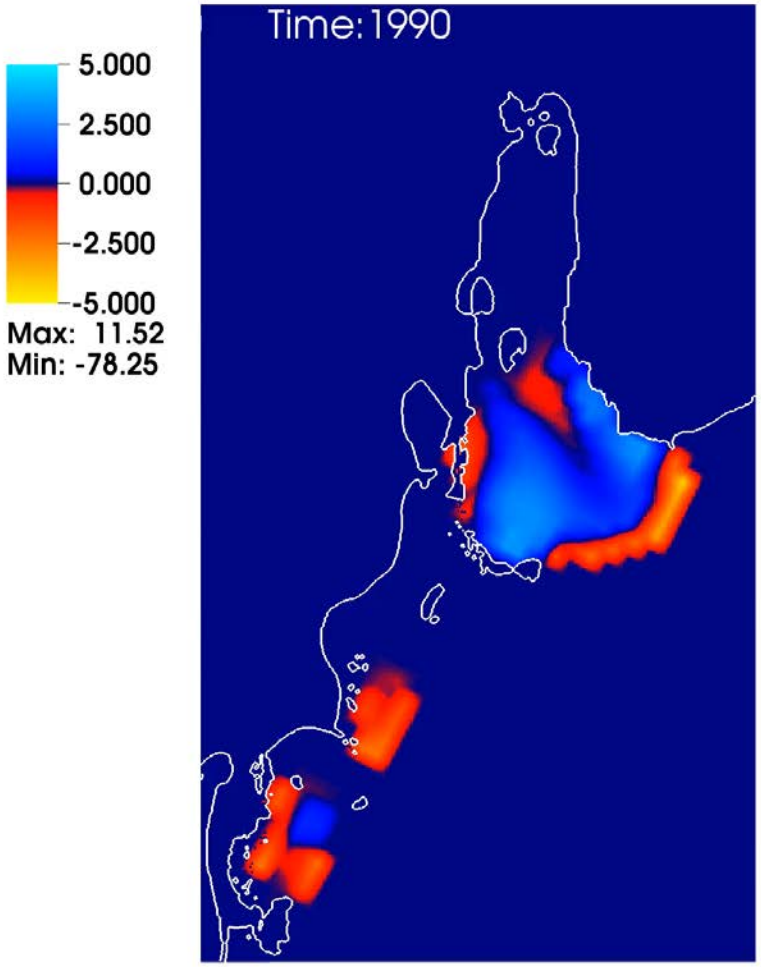
Ross:


DB: plot
Cycle: 710 Time:1990
Pseudocolor
Var: basalThicknessSource
5.000
2.500
0.000
-2.500
-5.000
Max: 11.52
Min: -78.25
Y-Axis (x10^6)
X-Axis (x10^6)
2.4
2.6
2.8
3.0
3.2
3.4
1.8
2.0
2.2

Totten:



Totten:



Next steps

- Push on with current run (at least to 20 years)
- More realistic climatology/forcing leading to “real” projections
- Insatiable need for better topography/bathymetry, etc.
- Hopefully by AGU…

Conclusions

- POP2x+BISICLES=POPSICLES coupled model
- Performing "high-resolution" pan-Antarctic simulations
  - Full Southern Ocean (0.1 degree)
  - Full-continent Antarctica (500m)

- Issues arising from coupled runs:
  - Need better subshelf bathymetry/geometry (enormous progress, though!)
  - Ocean forcing problematic

- Can still see effects of coupled ice-ocean interactions

Thank you!

Extras

Computational Cost

- Run on NERSC's Edison

- For each 1-month coupling interval:
  - POP: 1080 processors, 50 min
  - BISICLES: 384 processors, ~30 min
  - Extra "BISICLES" time used to set up POP grids for next step

- Total:
  1464 proc x 50 min = ~15,000 CPU-hours/simulation year
  (~1.5M CPU-hours/100 years)

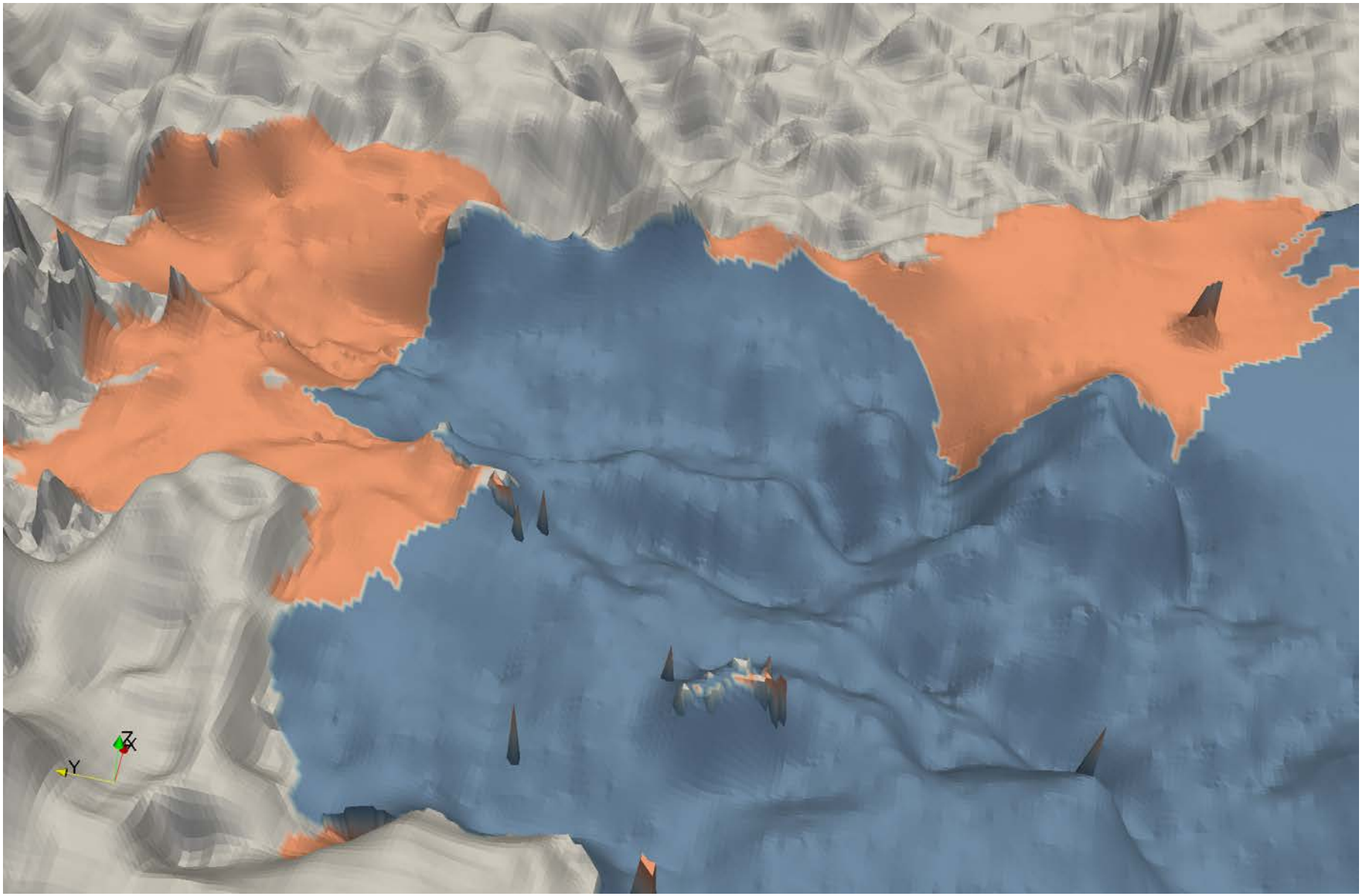
Motivation: Projecting future Sea Level Rise

- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.

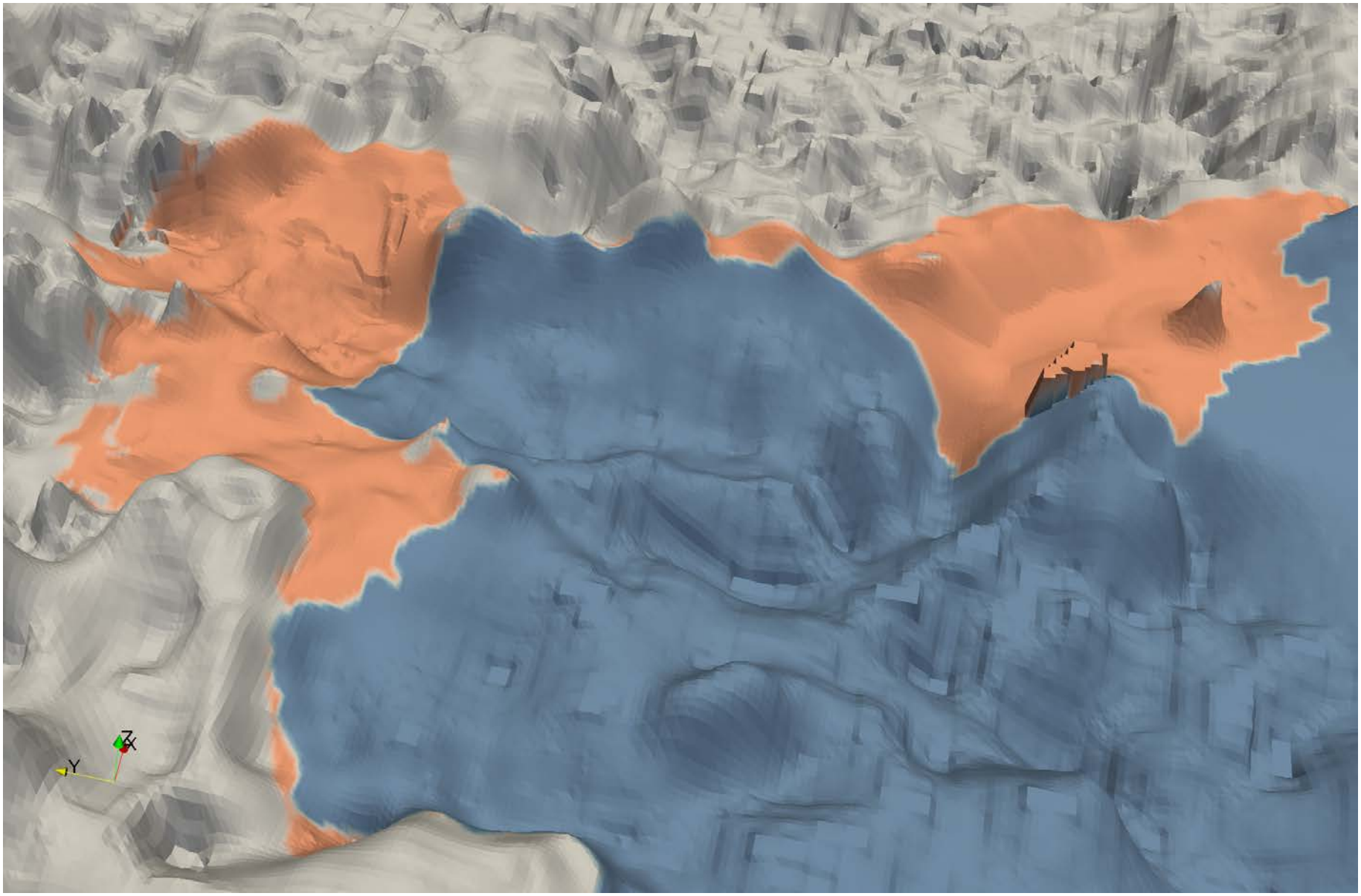
- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- Paleorecord implies that WAIS has deglaciated in the past.

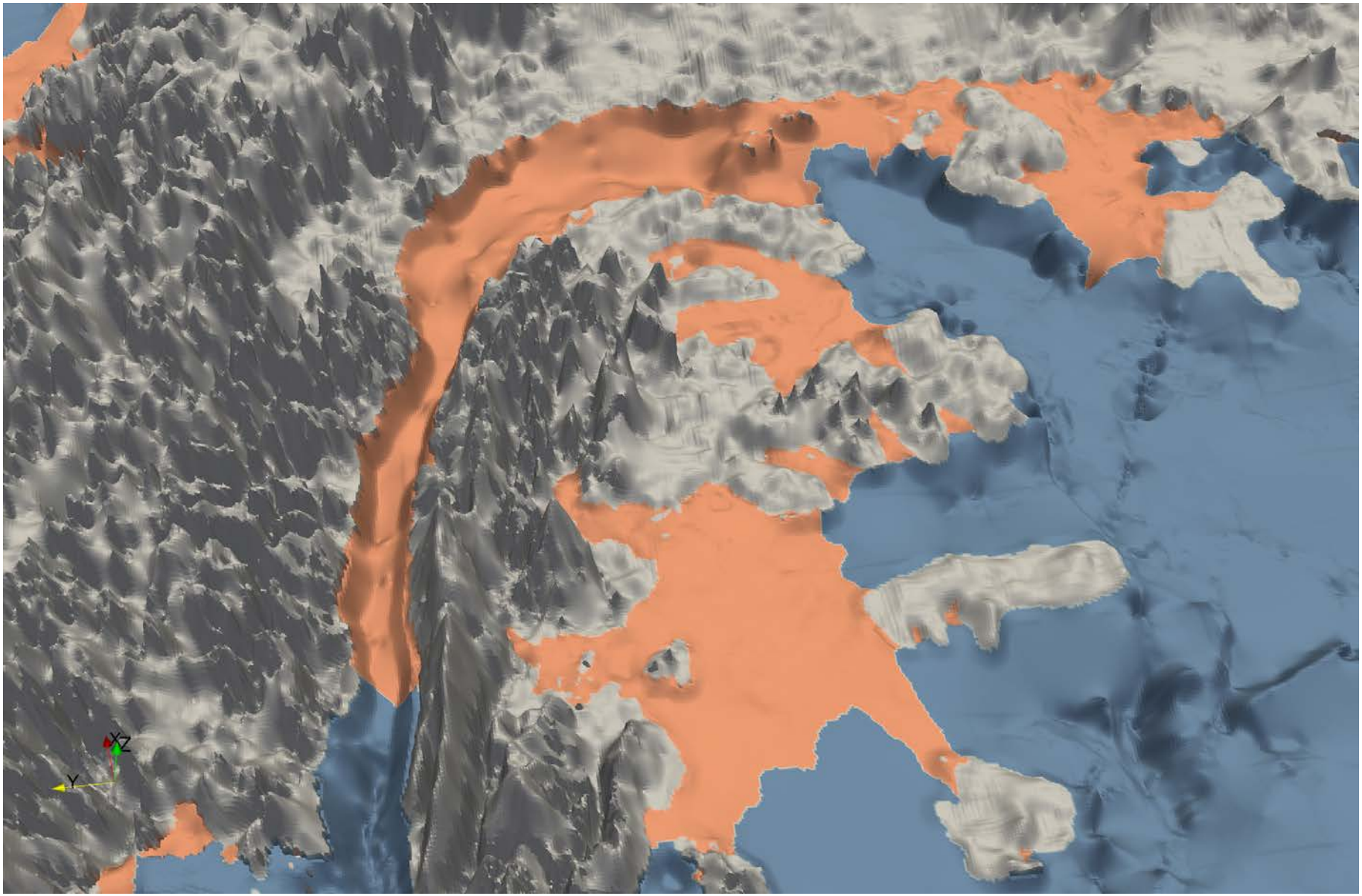
ASE (orig)



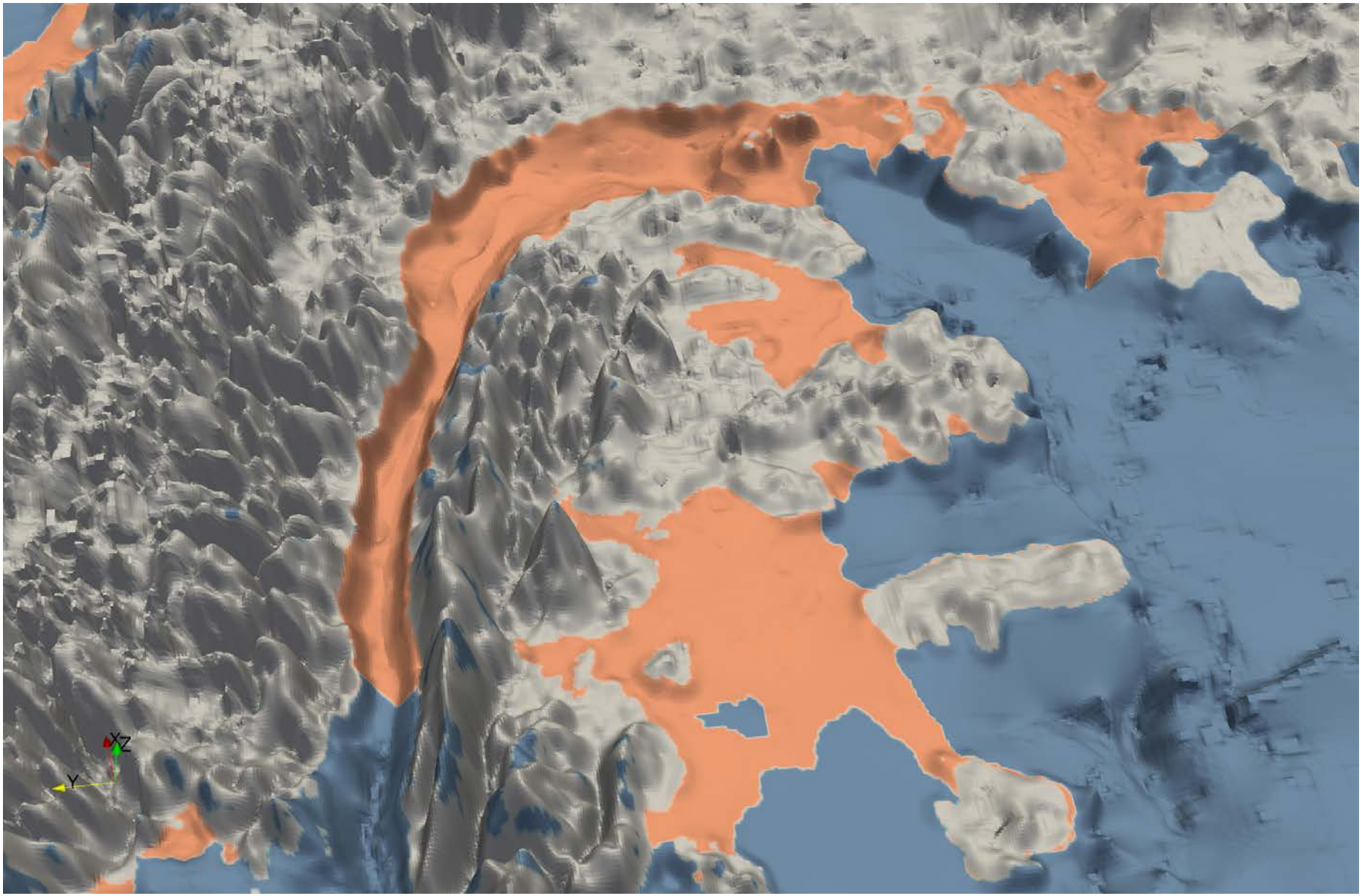
ASE (modified)



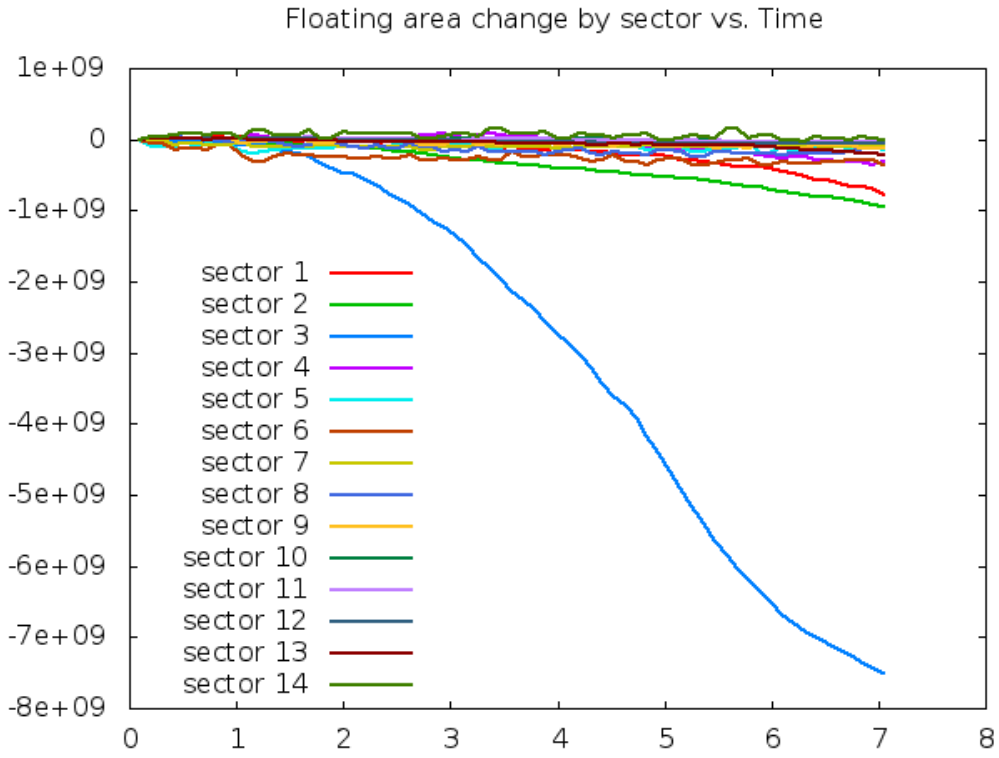
George VI, Stange (Bedmap2)



George VI, Stange (modified)

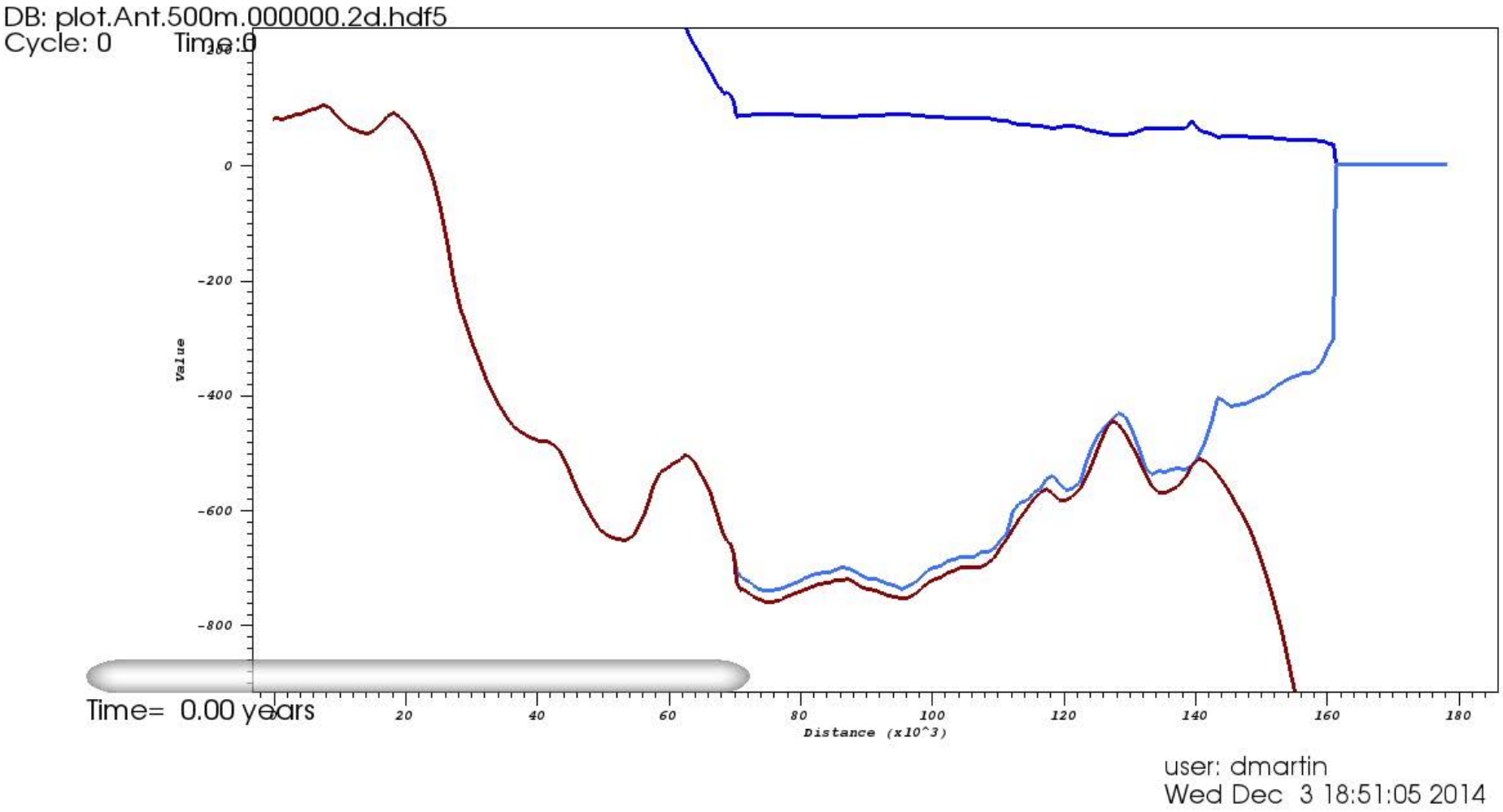


What happened?



- Response dominated by loss of floating area in a few sectors (**Getz**!)
- This was a **warming** scenario?
- **What happened?** (Getz sector!)

Getz Ice shelf -- Regrounding instability



Getz Ice shelf -- Regrounding instability (cont)

What happened?

- Bedmap2 – poorly constrained subshelf bathymetry
  - "Made stuff up" -- reasonable from the ice-sheet perspective
  - Resulted in very thin (< 100m) subshelf cavities under the ice
- Nominal/standalone POP2x melt rates fairly high
- Large synthetic accumulation field to balance melt and keep shelf in steady state
- Time-dependent runs – ***instability***
  - Small relative fluctuations in melt-rate forcing can result in thickness changes which are **O(** cavity thickness)
  - Localized grounding
  - Subself melting turns off – unbalanced (and large!) accumulation
  - Leads to more regrounding -> more unbalanced melt….

Other changes

- Switch to more-physical SMB field (Arthern)
  - abandon attempt to put AIS in “steady state”

- Switch to CORE v2 “Normal year” forcing

Work in progress – about 5 years in…